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The EllipSys2D / 3D code and its application within wind turbine aerodynamics

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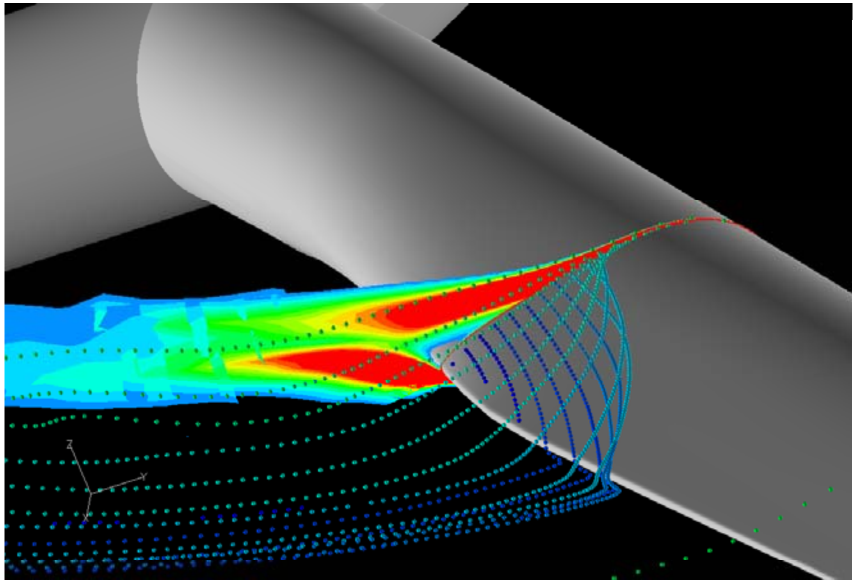

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Outline of talk

- Aerodynamics of wind tubines
- EllipSys2D/3D flow solver
  - Components of the solver
  - Grid generation
- Applications
  - Airfoil Aerodynamics
  - Transition modeling
  - Dynamic stall
  - Deep stall aerodynamics
  - Rotor aerodynamics
  - Aeroelasticity
  - Flow over terrain

Aerodynamics for wind turbines

- Flow over complex terrain
- Rotor aerodynamics
- Rotor/Tower interaction
- Wake aerodynamics
- Airfoil Flows
- Laminar/turbulent transition
- Hysteresis phenomena, dynamic stall
- Damping and stability
- Aeroelasticity

Ellipsys2D / 3D flow solver
Navier-Stokes Solver

Based on the Navier-Stokes equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_j) = 0 \ ,$$

$$\frac{\partial}{\partial t}(\rho U_i) + \frac{\partial}{\partial x_j}[\rho U_i U_j] - \frac{\partial}{\partial x_j}\left[(\mu + \mu_t)\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] + \frac{\partial P}{\partial x_i} = S_{\boldsymbol{v}} \ ,$$

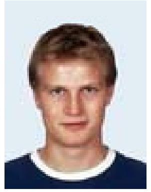
$$\frac{\partial}{\partial t}(\rho \Phi) + \frac{\partial}{\partial x_i}[\rho U_i \Phi] - \frac{\partial}{\partial x_i}\left[(\mu + \frac{\mu_t}{\sigma_\Phi})\frac{\partial \Phi}{\partial x_i}\right] = S_\Phi \ .$$

Ellipsys2D / 3D flow solver
The choices in the solver

- Incompressible Navier-Stokes
- Finite volume code (non-staggered)
- Cartesian or polar velocity components
- Patched multi-block grids (new overset option)
- Pressure/Velocity formulation
- Steady/Unsteady algorithm
- Moving Mesh/Moving Frame
- Turbulence Modelling RANS/DES
- Acceleration techniques: grid sequence/multigrid
- Parallellized using MPI for distributed computers







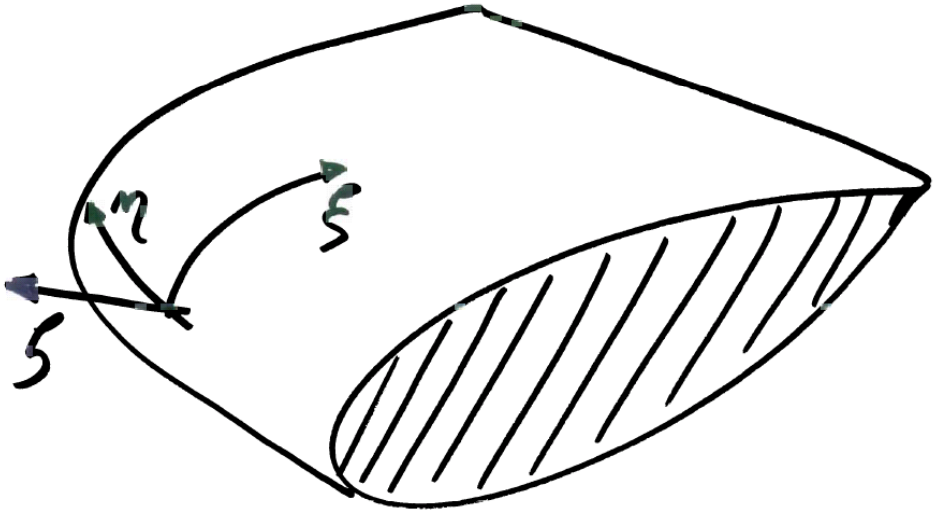

EllipSys2D / 3D flow solver
Computational grids

HypGrid2D, HypSurf

$$
\begin{aligned}
r_\xi \cdot r_\eta &= 0 \\
\hat{n} \cdot (r_\xi \times r_\eta) &= \Delta S \\
\hat{n} \cdot r_\eta &= 0
\end{aligned}
$$

HypGrid3D

$$
\begin{aligned}
r_\xi \cdot r_\zeta &= 0 \\
r_\eta \cdot r_\zeta &= 0 \\
J &= \Delta V
\end{aligned}
$$

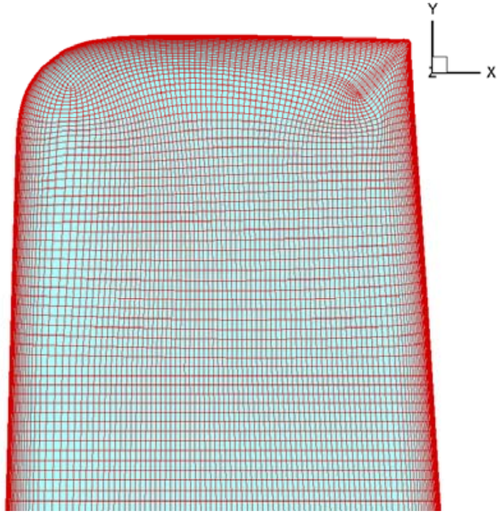


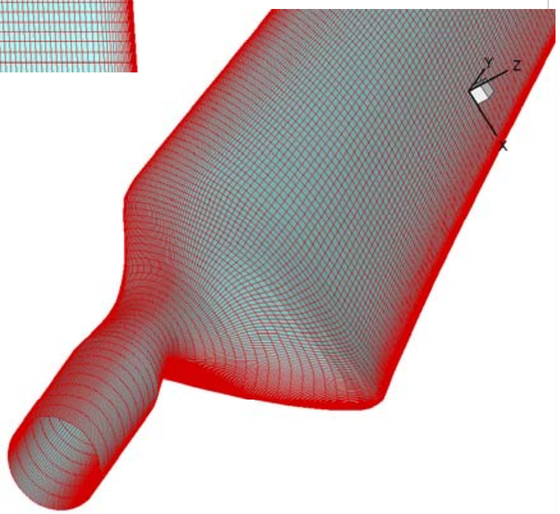
Smallest detail 1×10^{-5} m.

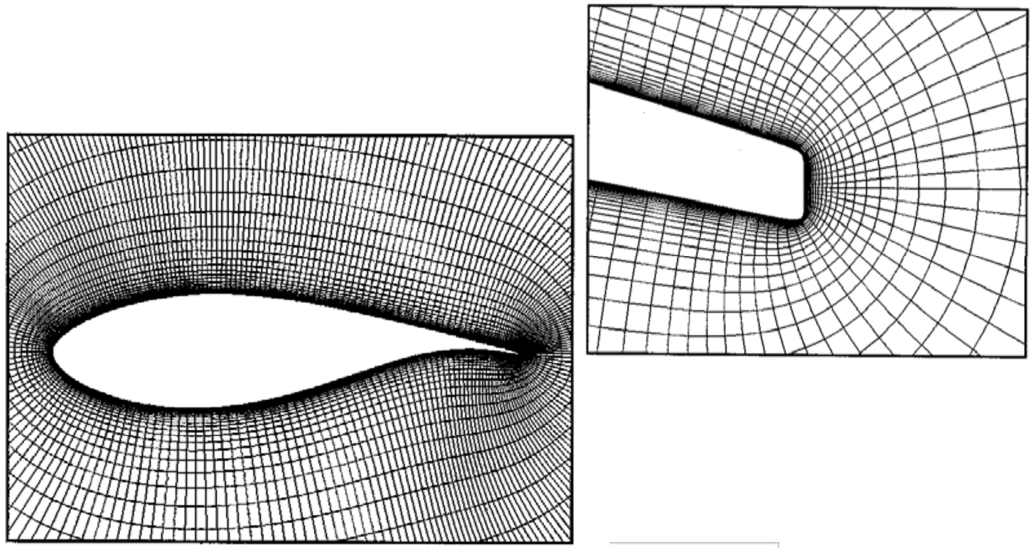
Largest scale ~500 m.

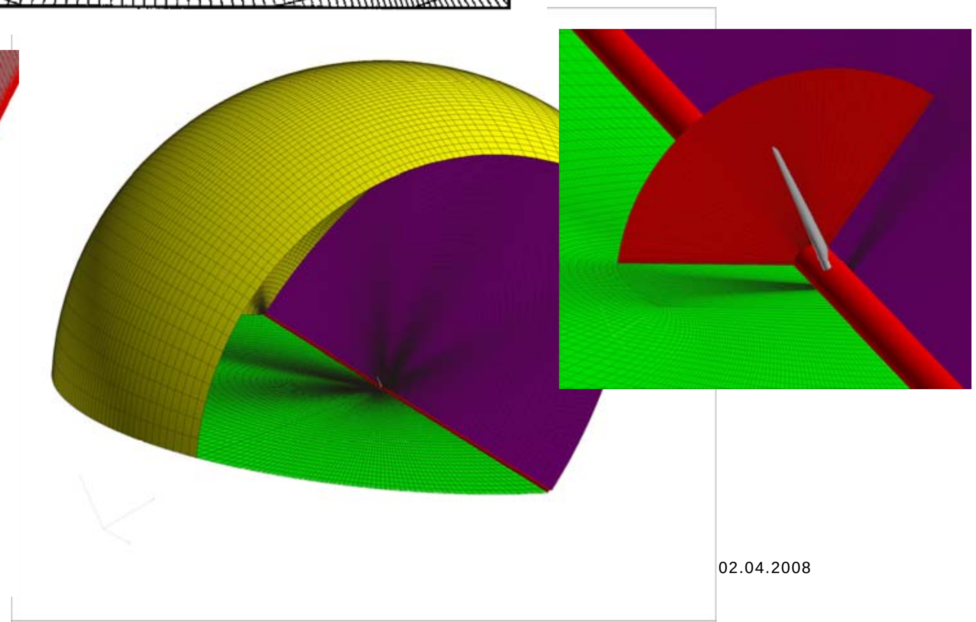
Typical number of cells 4-20 mio.

EllipSys2D / 3D flow solver
Grid Examples



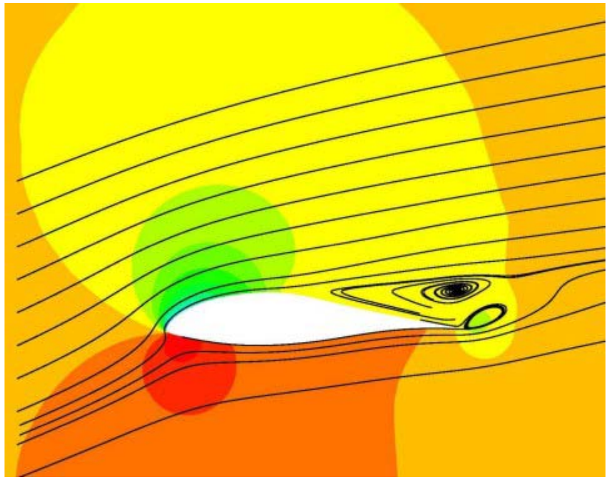


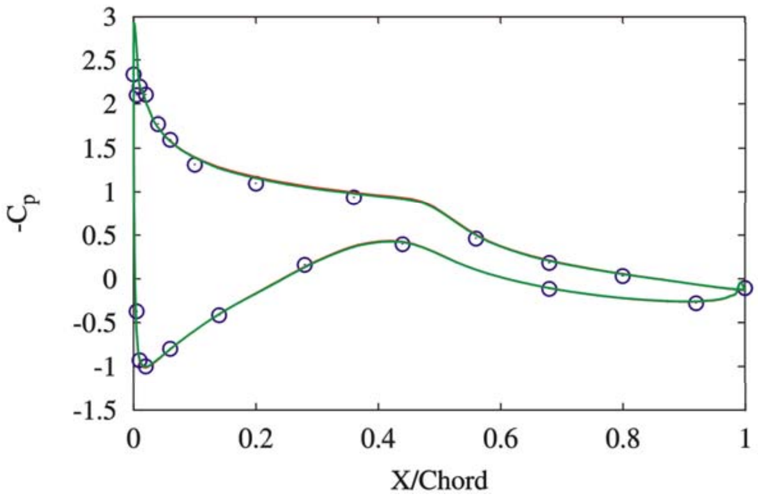


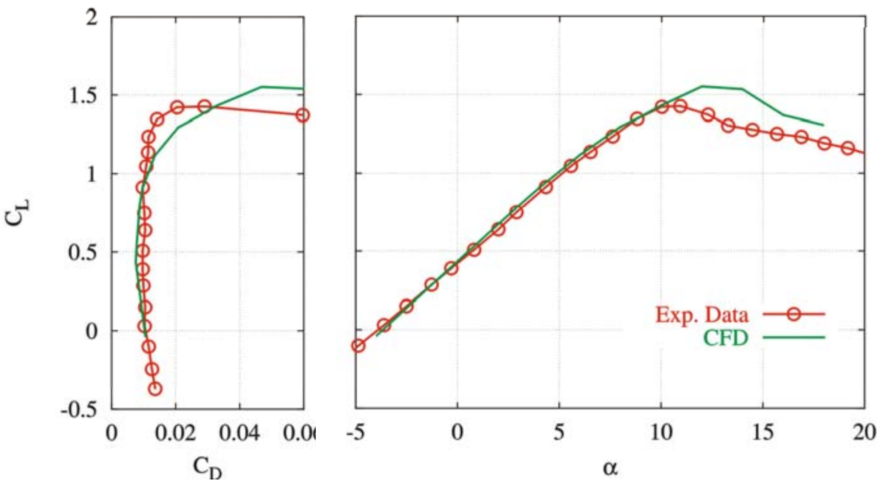


Airfoil Aerodynamics
2D applications

- Basic studies
- Cl/Cd/Cm for BEM computations
- Airfoil catalog
- Airfoil design and optimization
- Planning and conduction of measurements
- Laminar/turbulent transition
- Dynamic stall computations

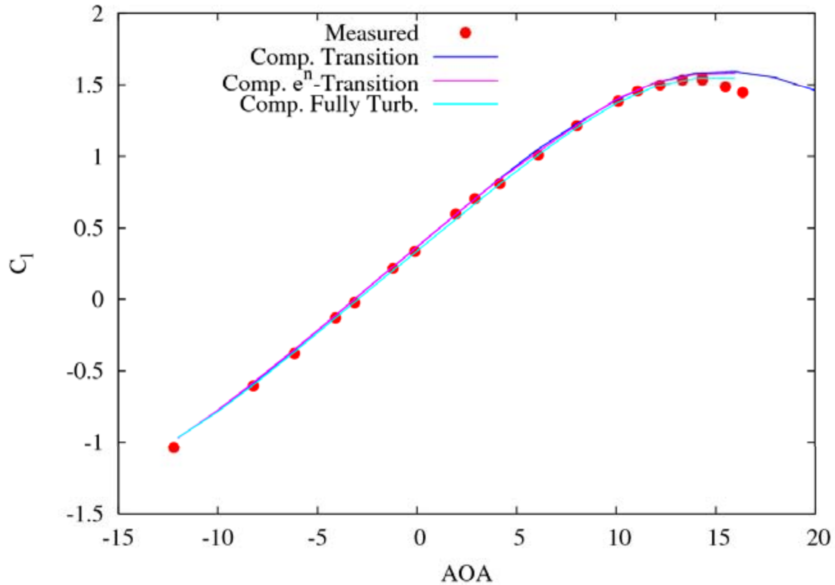


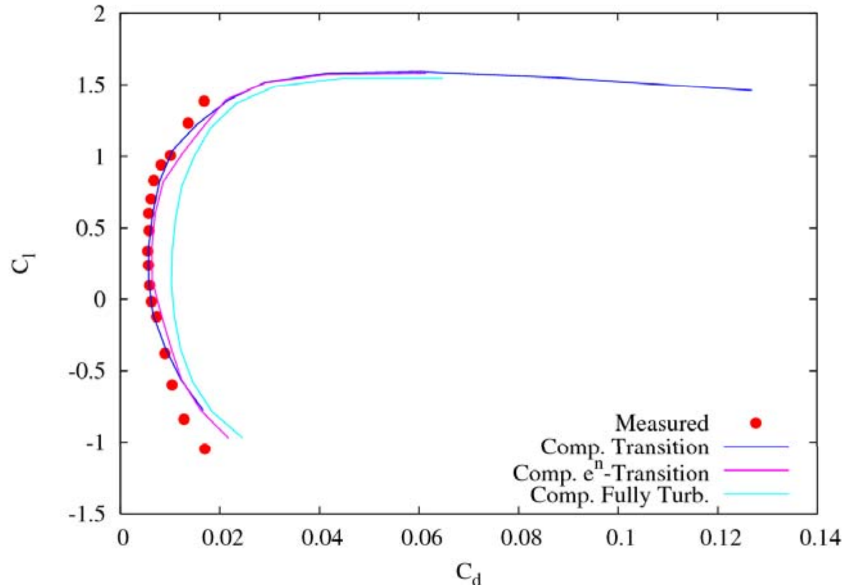


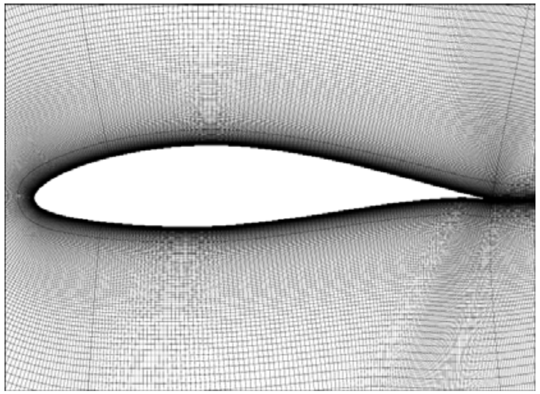


Airfoil Aerodynamics
Laminar/Turbulent Transition

- NACA 63-415 Airfoil, Re=3 million, Ti=0.04%

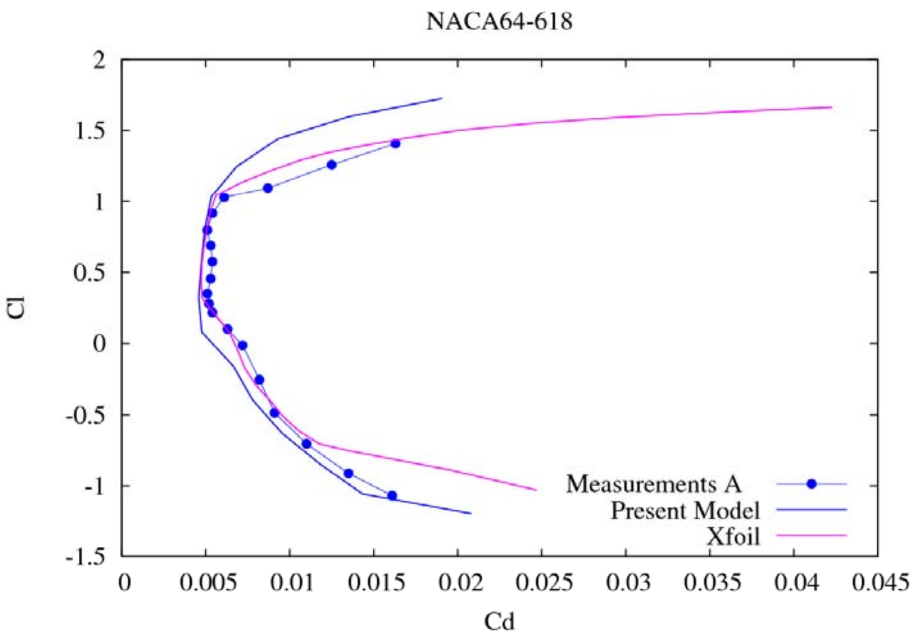


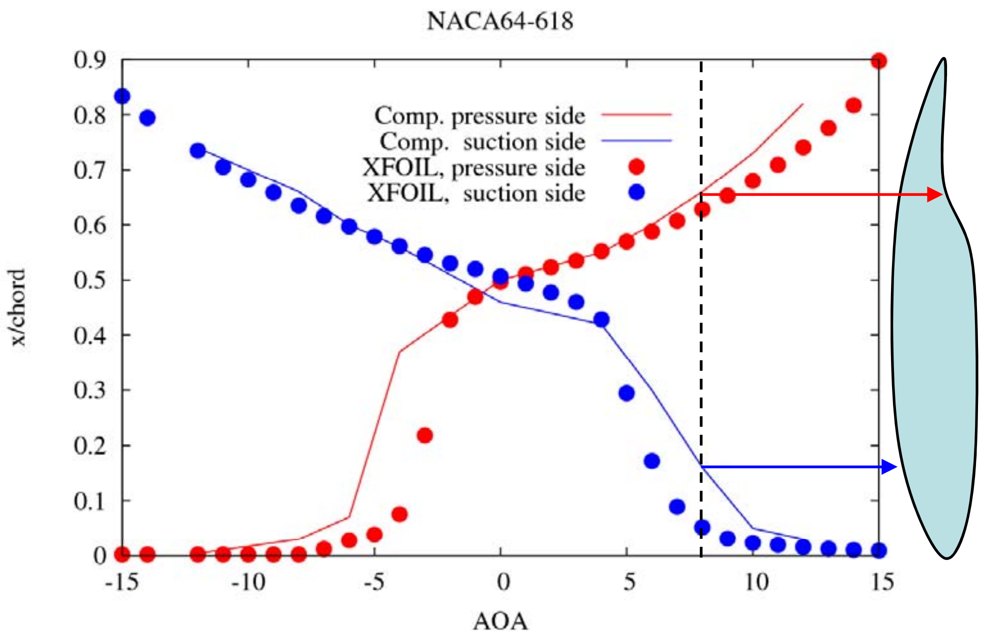




Airfoil Aerodynamics
Laminar/Turbulent transition

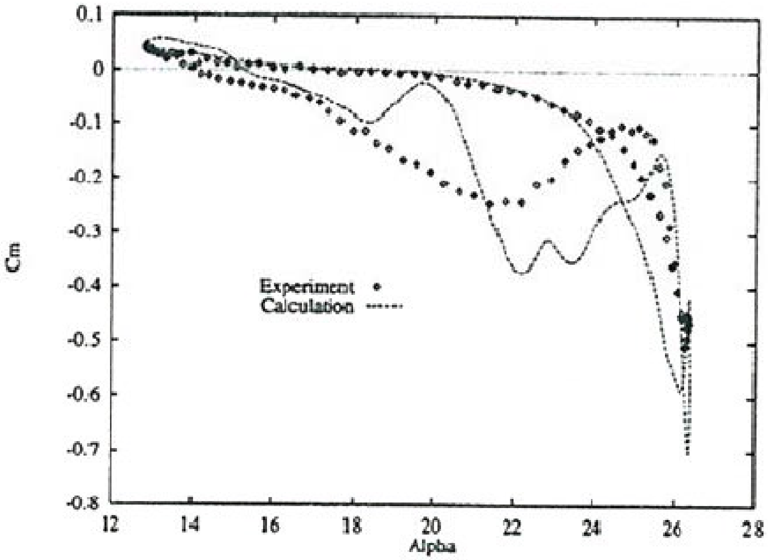
NACA 64-618, Re=6.0 million

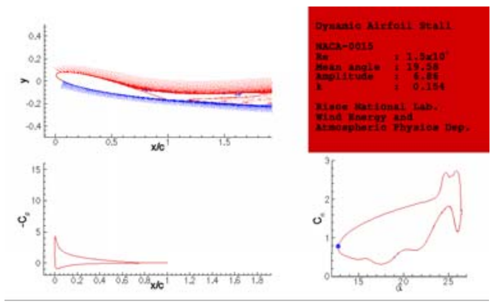


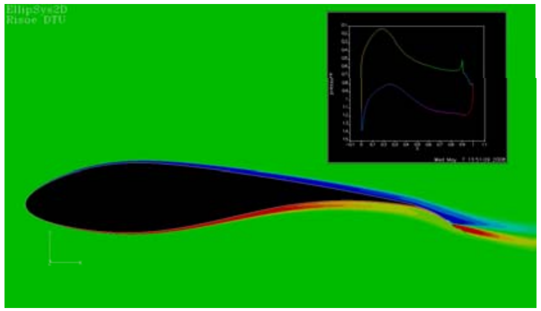


Dynamic stall

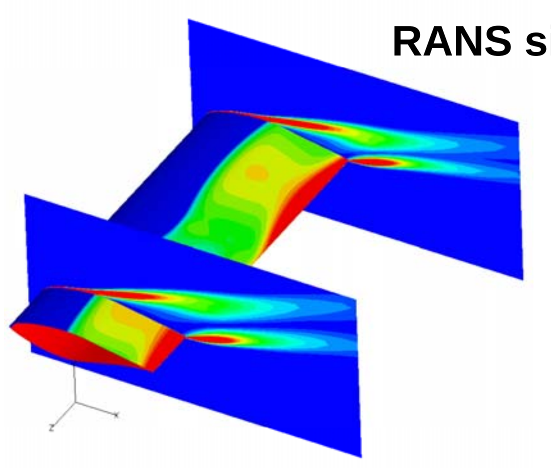
- Dynamic stall
- Stall characteristics
- Aerodynamic damping

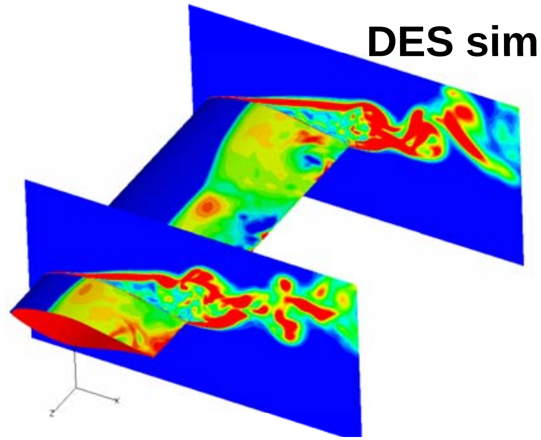




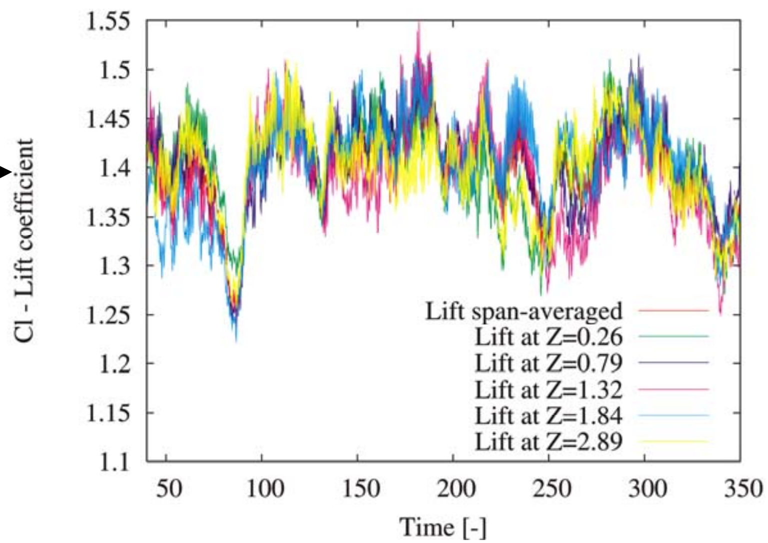


Deep stall aerodynamics
3D blade section in static stall





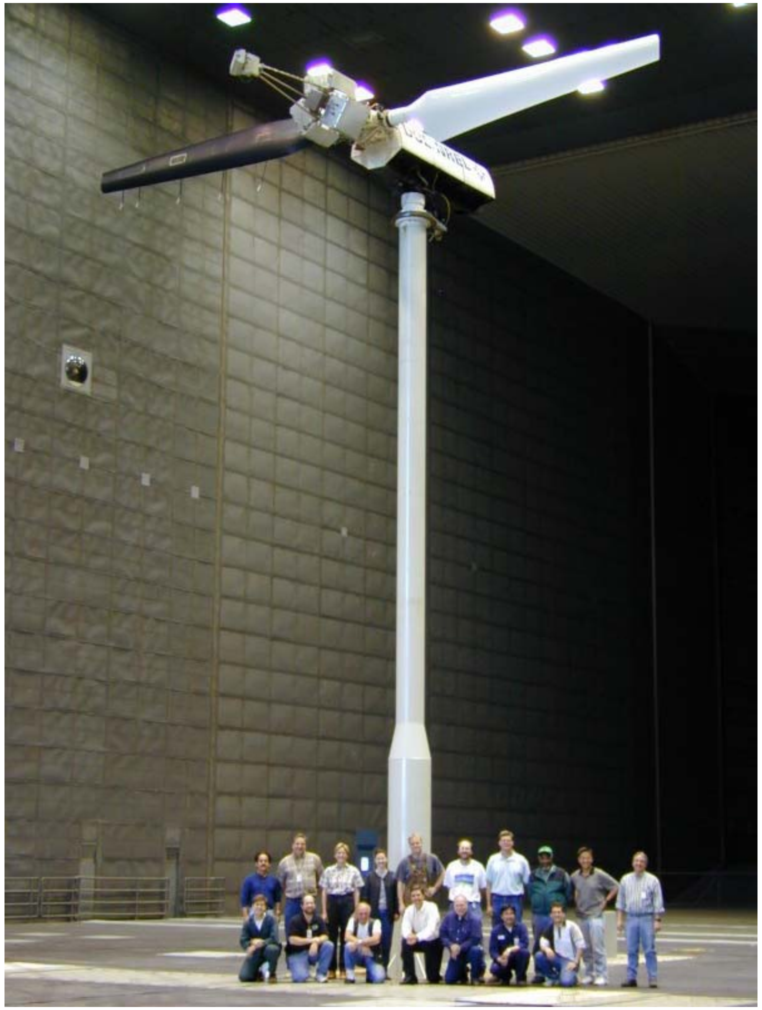
Unsteady lift time series



The development of a stochastic stall-model based on time series from DES-simulations is ongoing

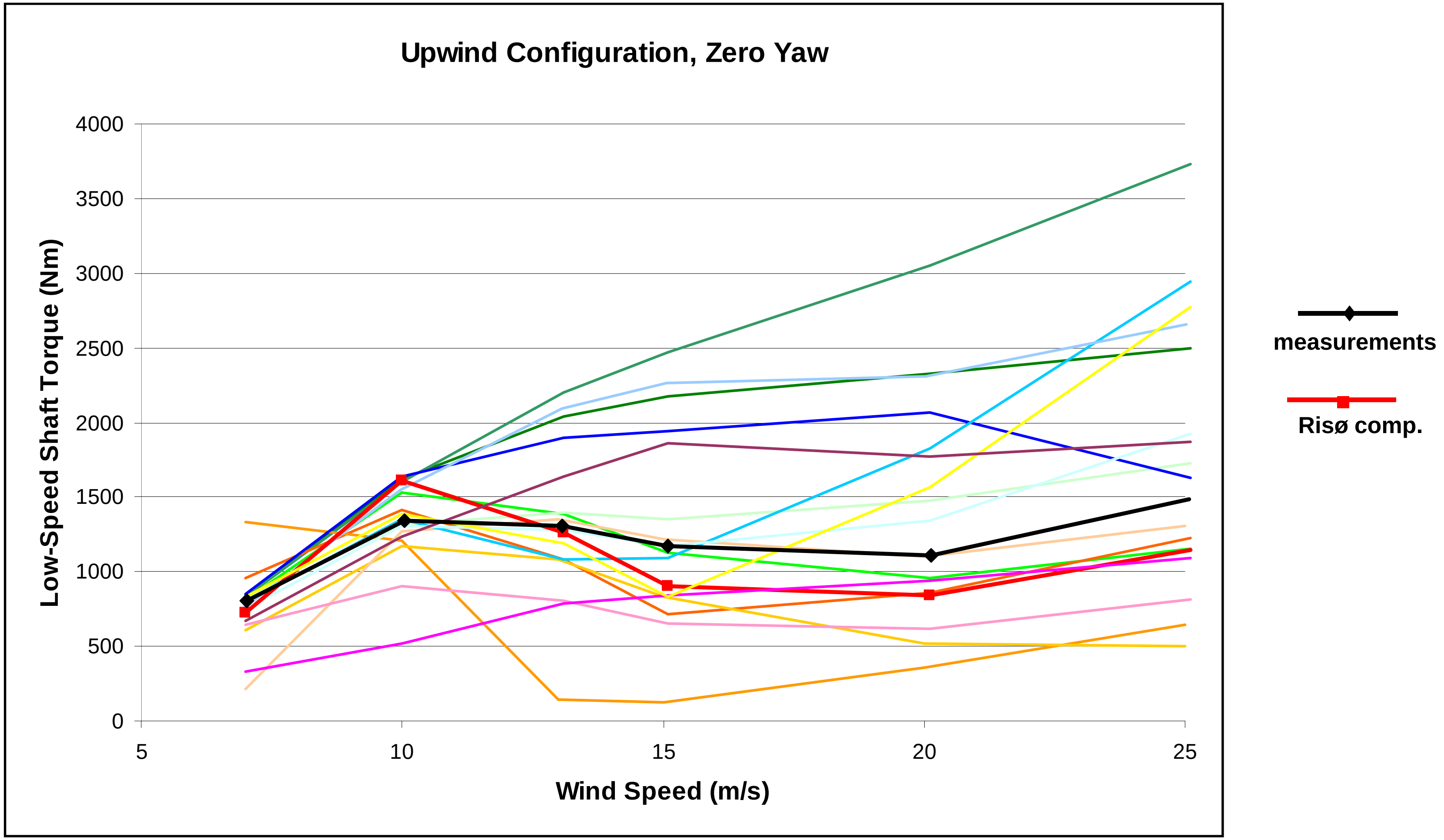
Rotor Aerodynamics
NREL / Nasa Ames test

NASA Ames Tunnel (24.4x36.6 m)

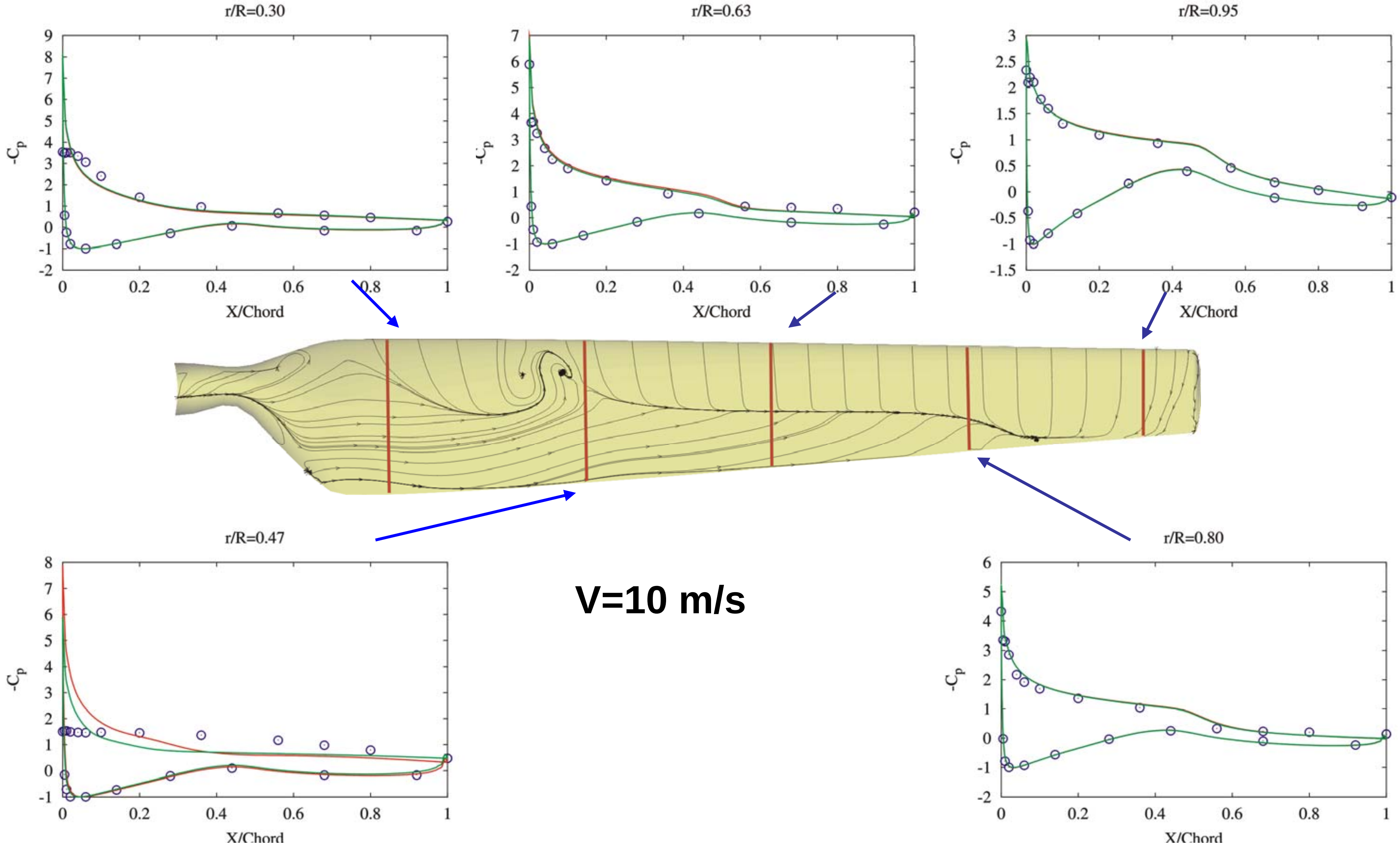


NREL Phase-VI Wind Turbine

Rotor Aerodynamics
Blind Comparison

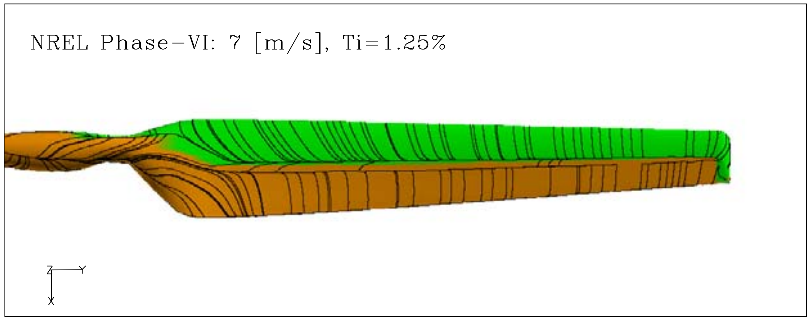


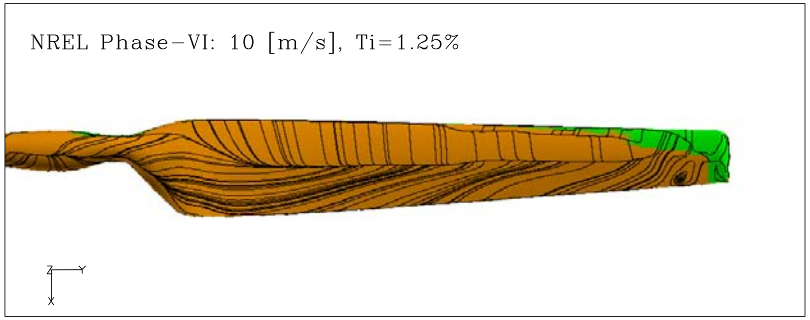
Rotor Aerodynamics
NREL Phase-VI rotor

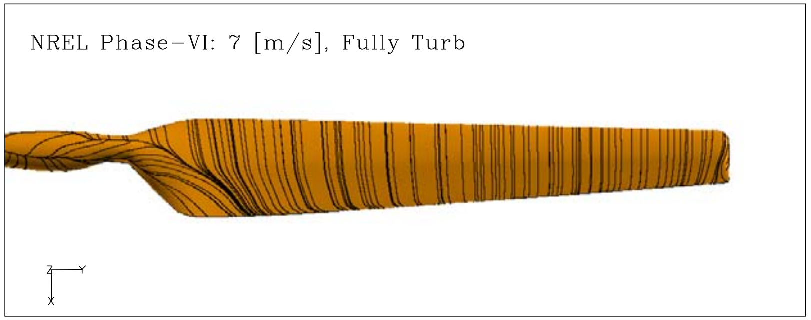


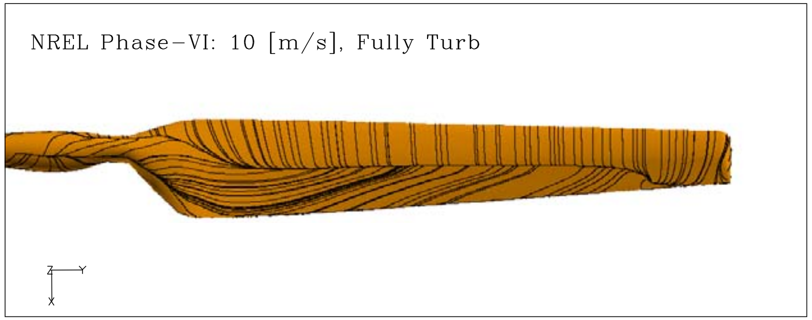
Rotor Aerodynamics
NREL Phase-VI rotor, Laminar/turbulent tran.

- Limiting streamlines





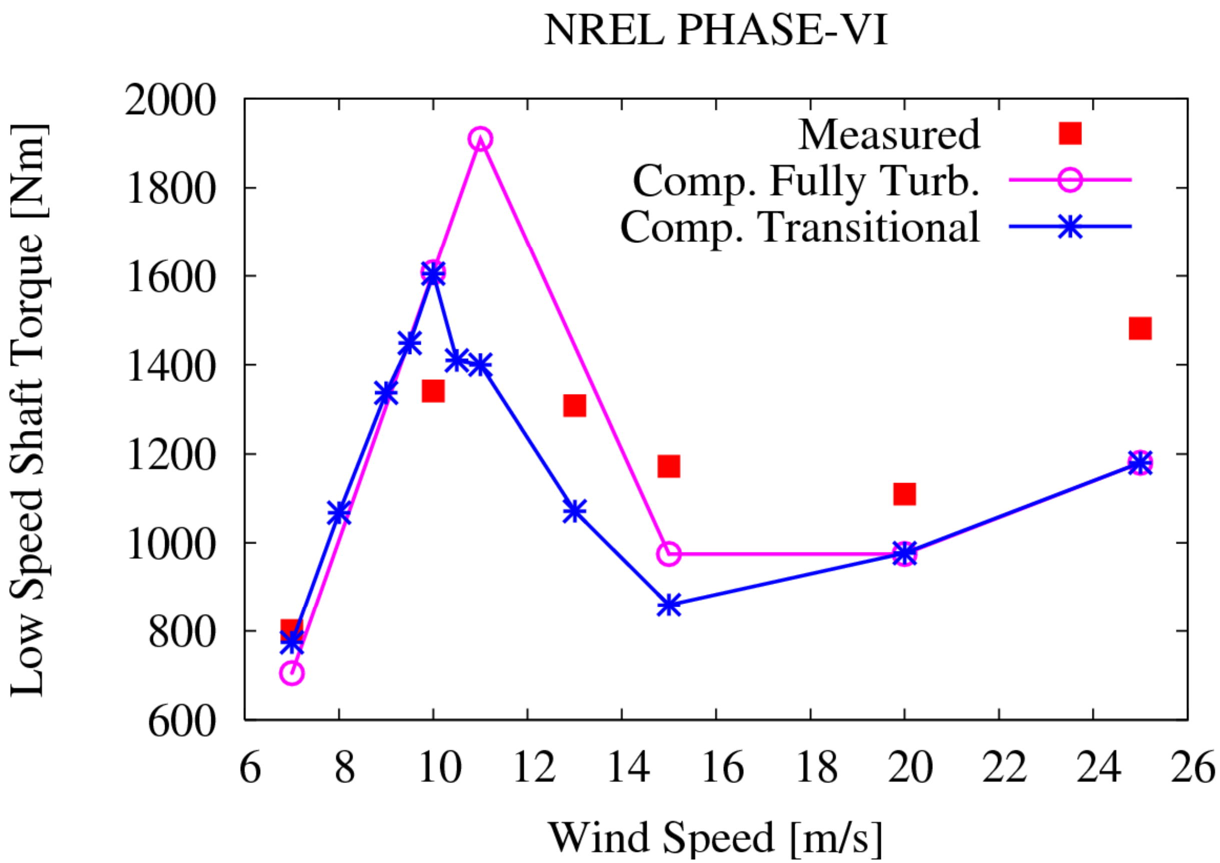


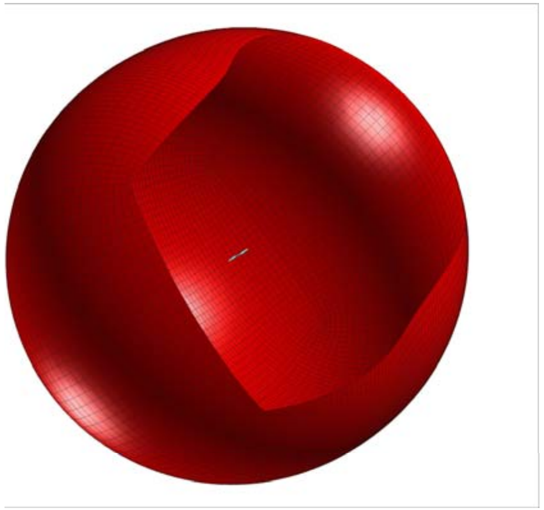


Rotor Aerodynamics

NREL Phase-VI rotor, Laminar/turbulent tran.

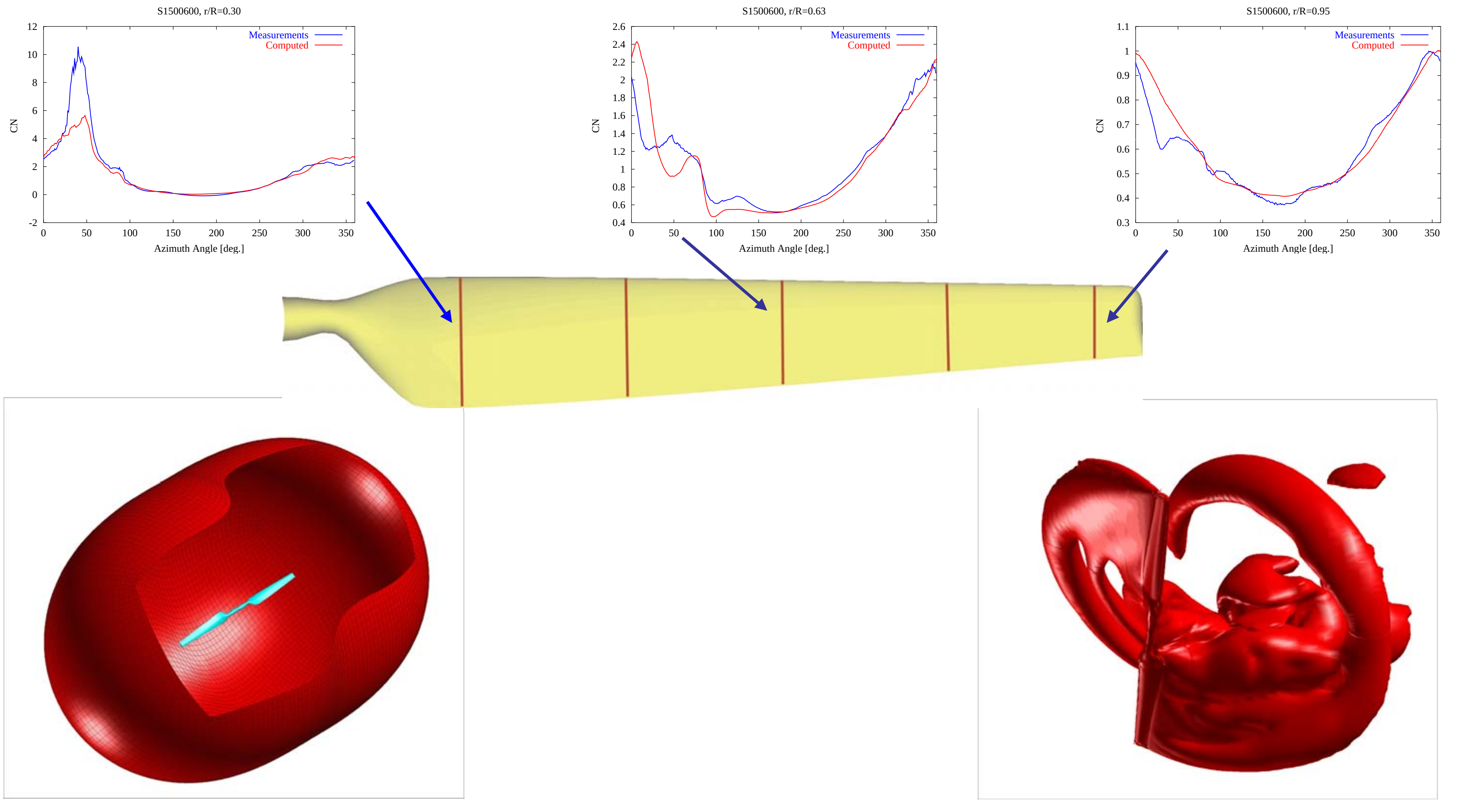
The transition model can improve the results in some cases





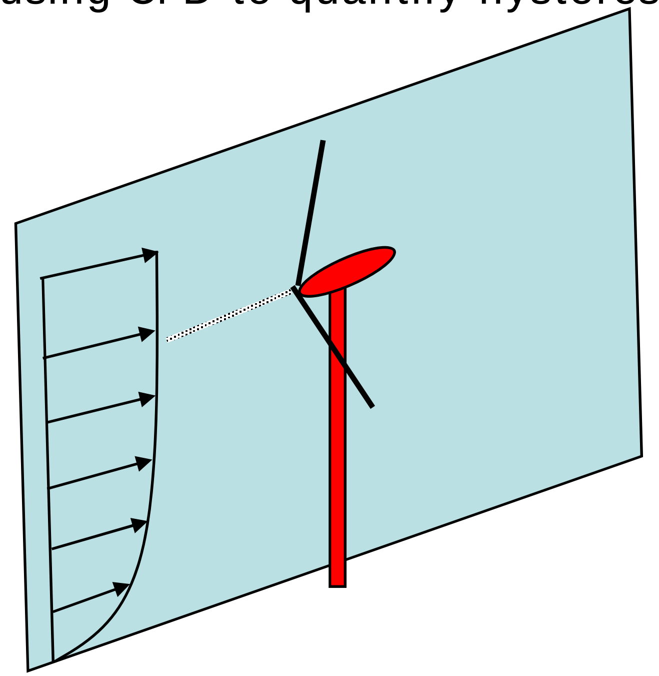
Rotor Aerodynamics
Yaw computations (60 degrees)

Azimuth variation of normal force

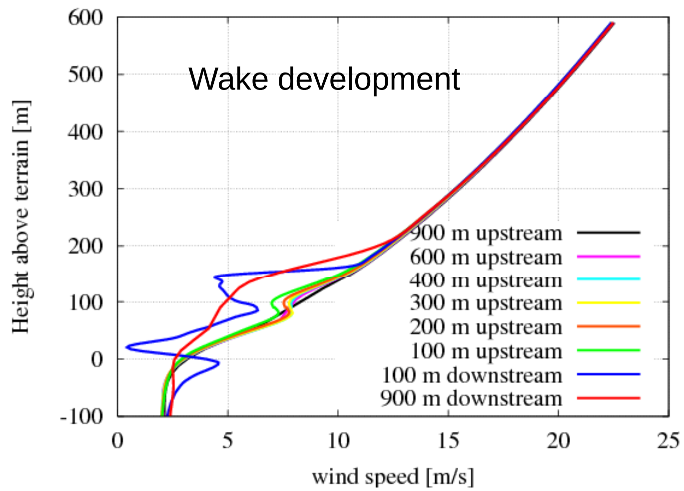


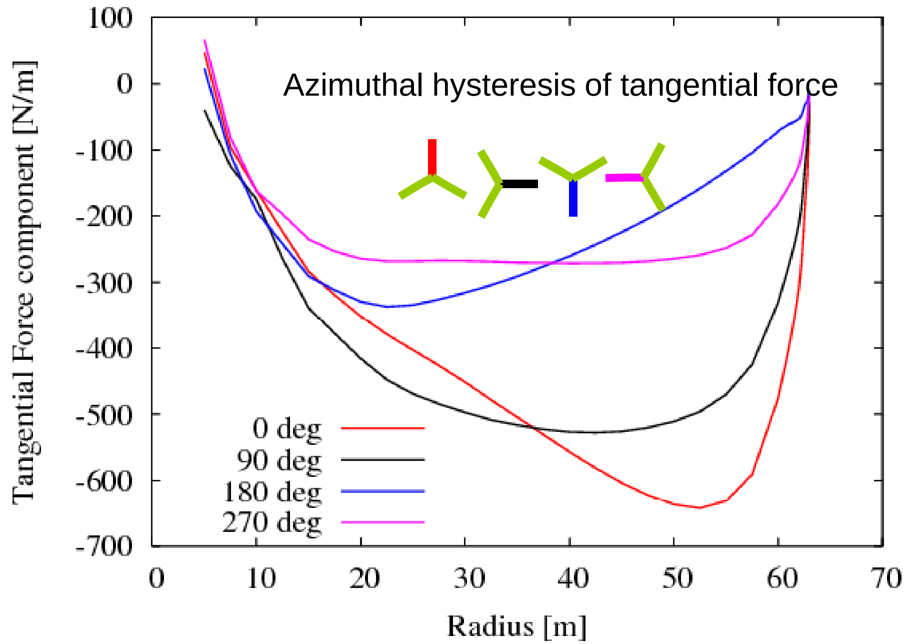
Rotor Aerodynamics
Rotors in atmospheric shear

- Rotors in shear flow has been studied using CFD to quantify hysteresis effects



$$U(z) = 8m/s \left(\frac{z}{90m} \right)^{0.55}$$





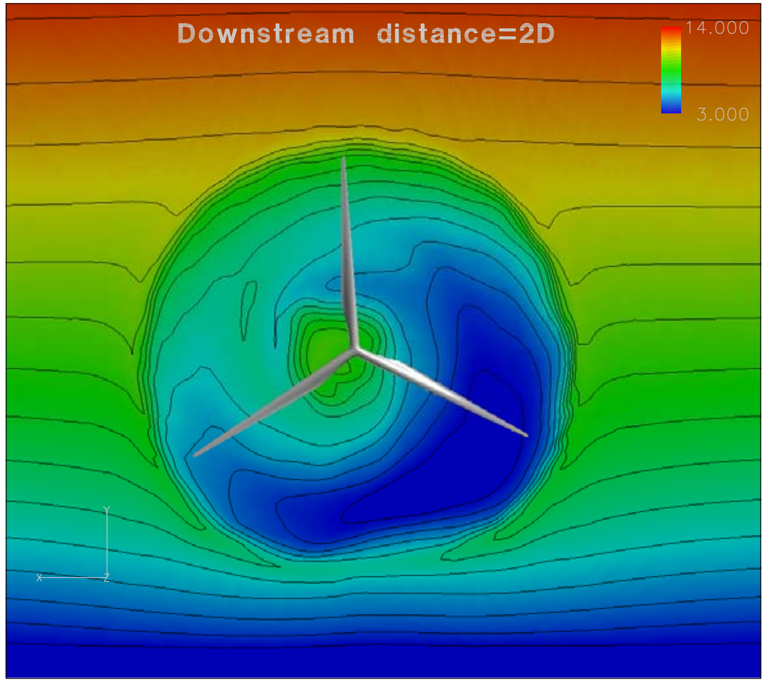
Rotor Aerodynamics
Rotors in atmospheric shear

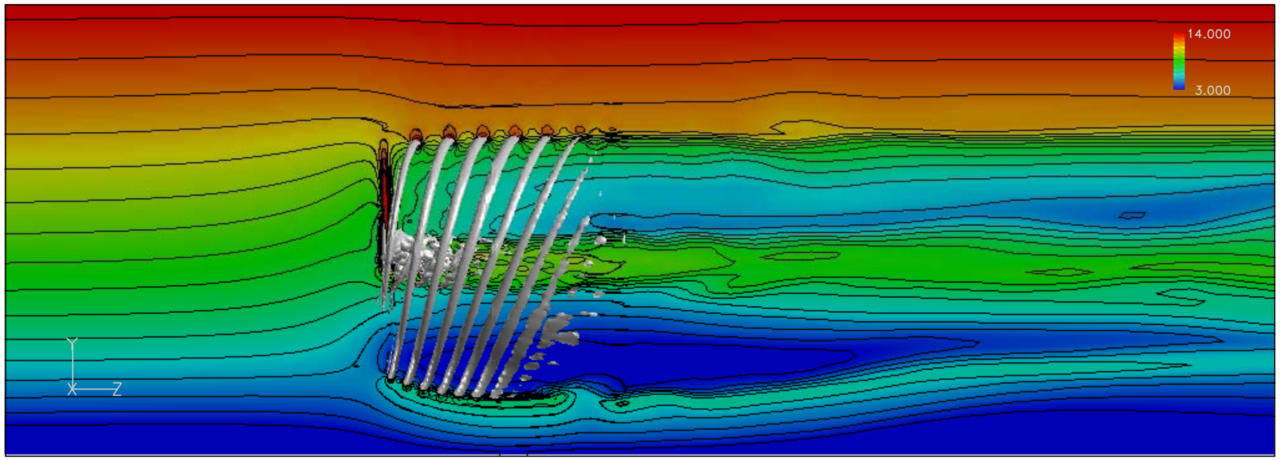
Results from CFD-analysis:

- causes aerodynamic hysteresis effects.

- Blade loads are different in horizontal position.

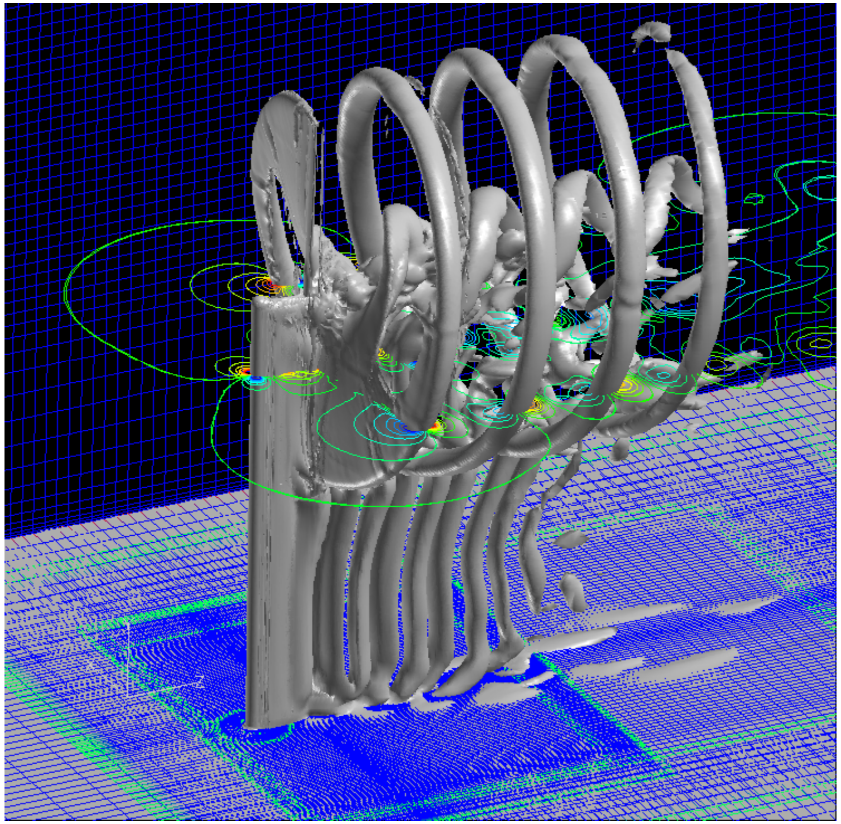
- Shear causes rotor yaw loads

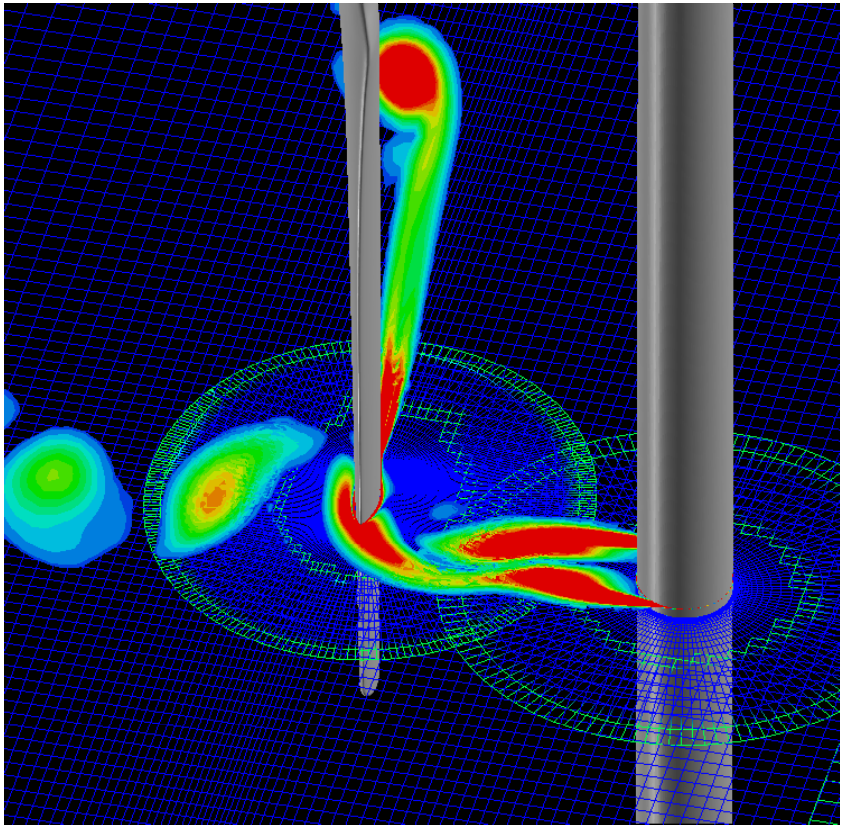




Rotor Aerodynamics
Rotor tower interaction

Details of blade-tower interaction investigated in order to:
- study lock-in phenomina
- develop semi-emperical tower shadow model and noise model

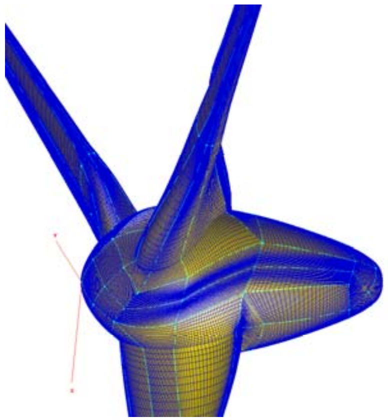


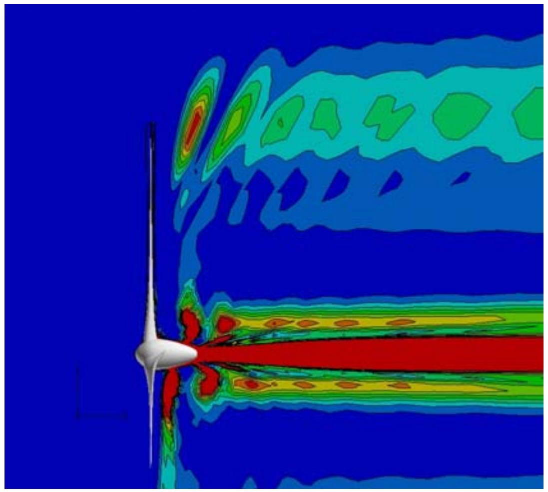


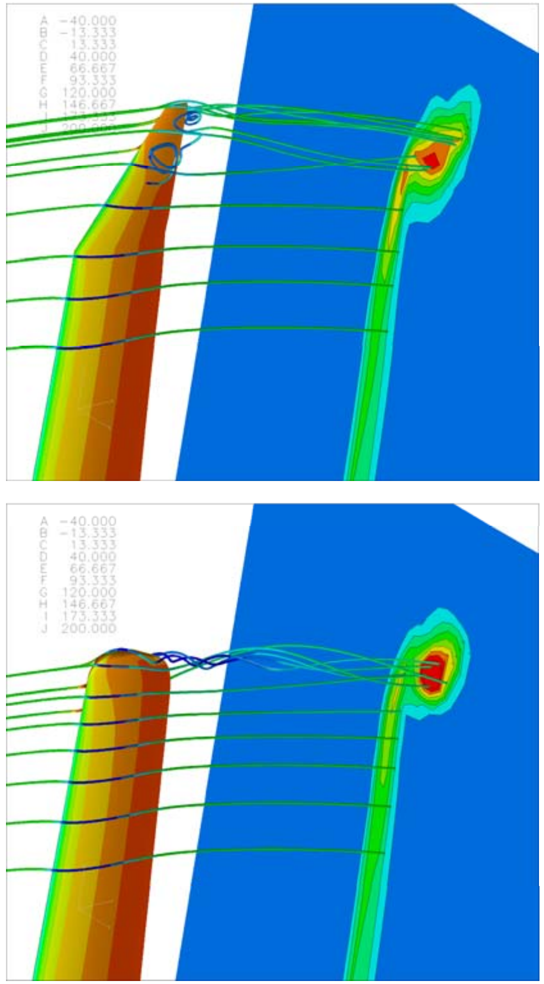
Rotor Aerodynamics
Detailled design analysis

Enercon E-70 design

Tip-design

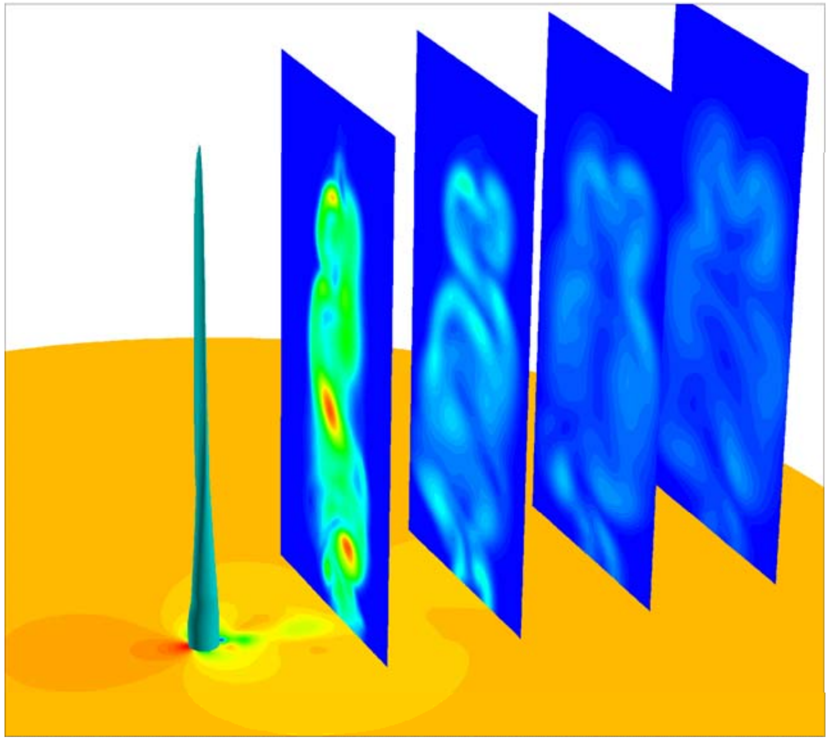


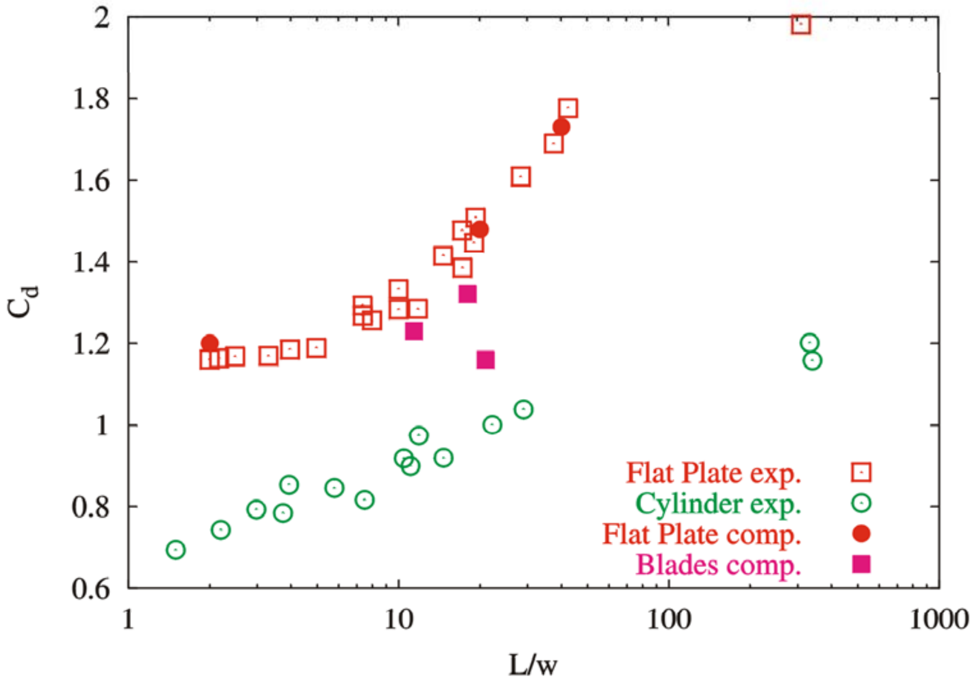




Rotor Aerodynamics
Drag values for parked wind turbine blades

Definition of aspect ratio
$L/w = L^2/Area$

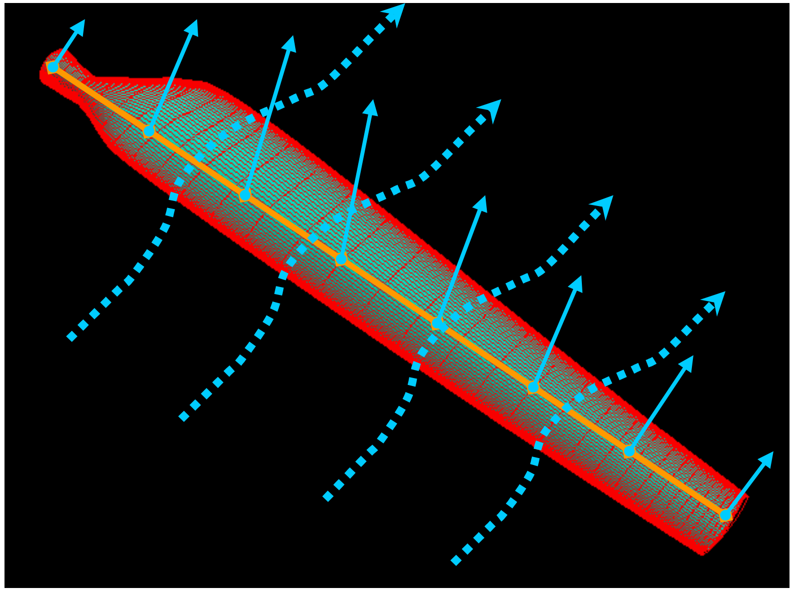


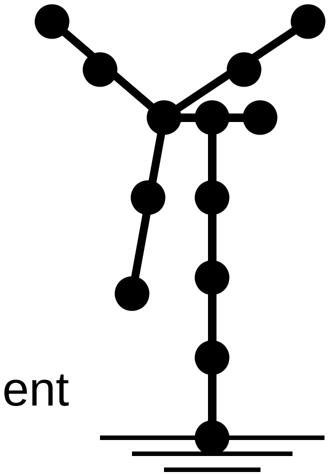


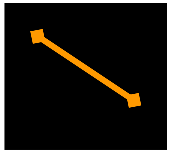
Blade	L/w	C_d comp.
LM8.2	11.4	1.23
LM19.1	18.0	1.32
Modern	21.0	1.16

Aeroelasticity

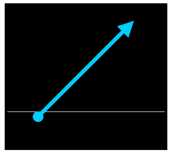
Coupling between EllipSys and HAWC



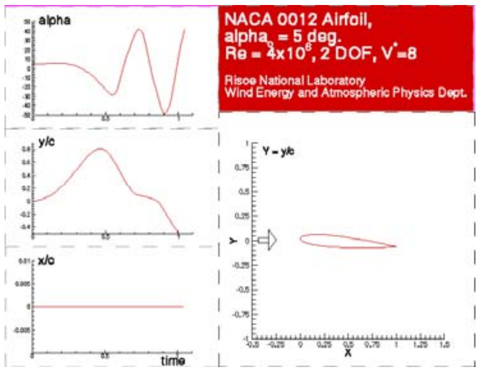


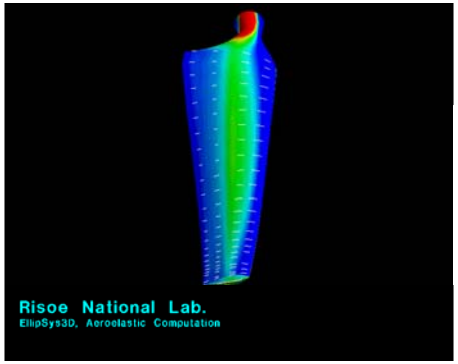


Beam element



Aerodynamic force



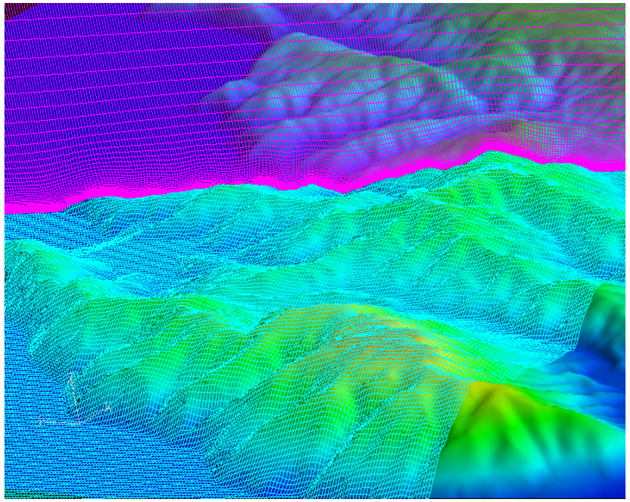


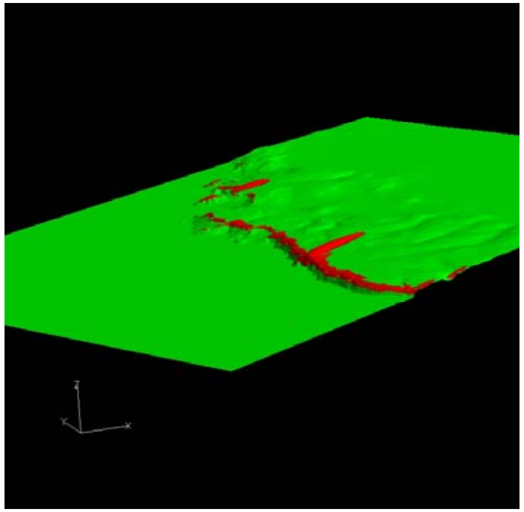
Site Analysis
Complex Terrain

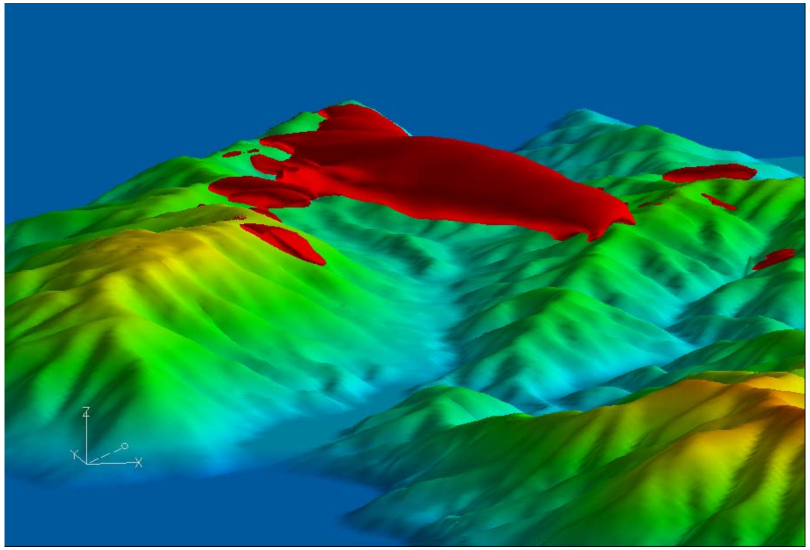
Terrains where WAsP is not suitable

Determining Speed-up, and flow inclination

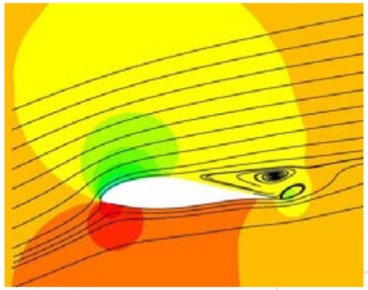
Evaluation of turbine positions, from levels of turbulent kinetic energy

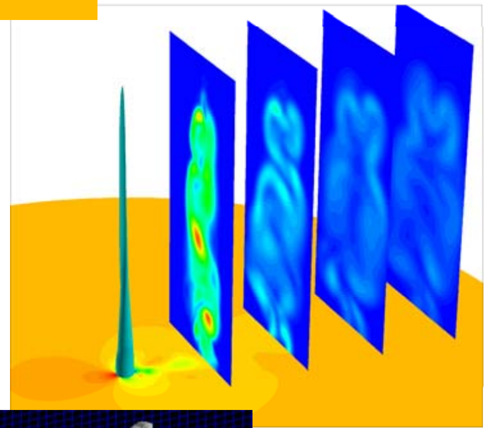




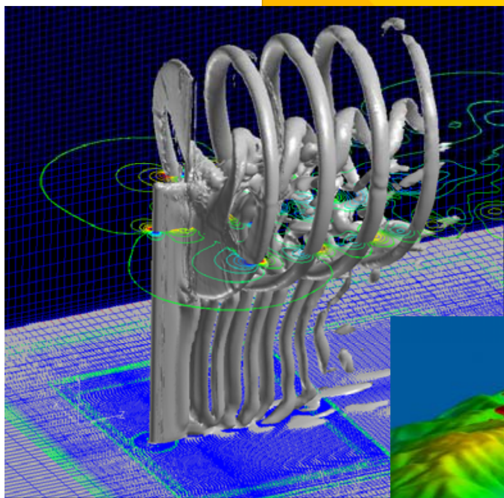


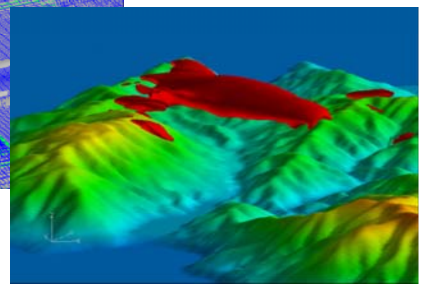
Conclusion

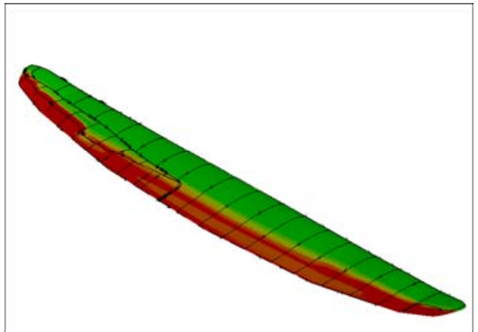




- The EllipSys code has been introduced
- A series of applications of the code to airfoil and rotor aerodynamics has been given, illustrating the versatility of the code
- The code is a general purpose solver and can be applied to other incompressible flows







A circling Supra wing